Conceptual Design of a Z-Pinch Fusion Propulsion System

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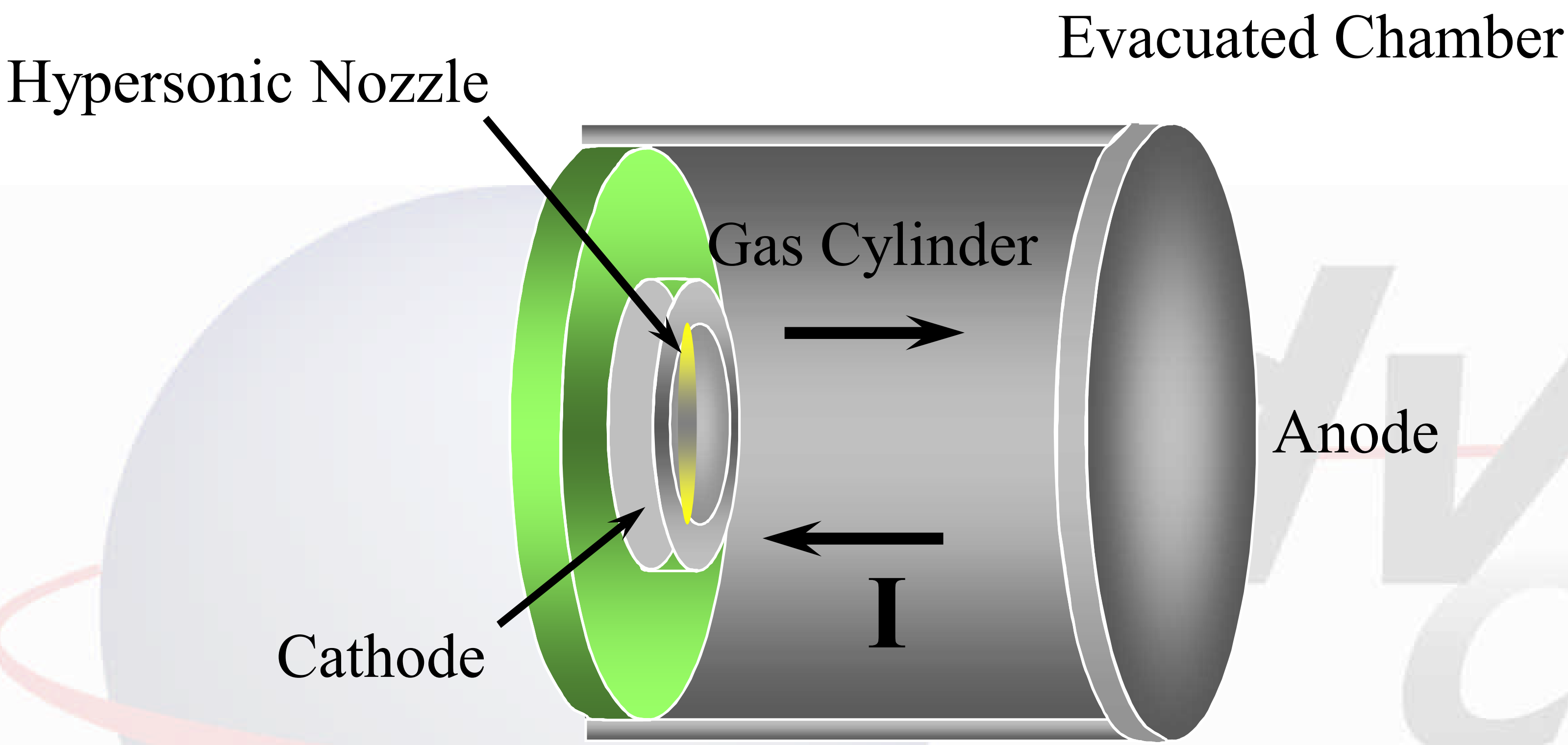
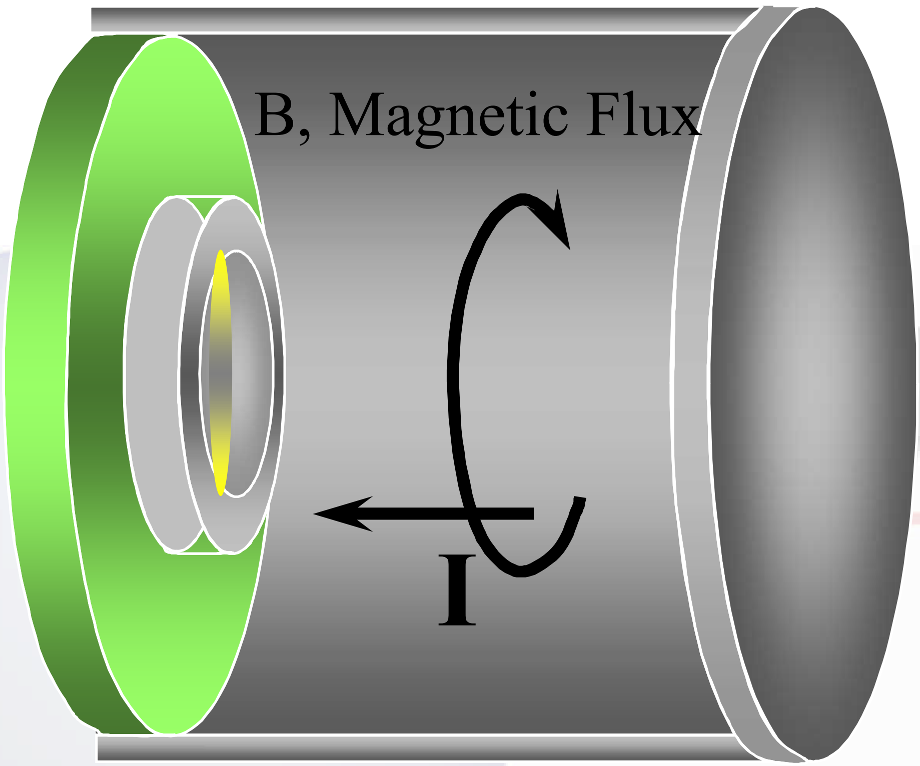
Z-Pinch Fusion: Background

- Nuclear weapon x-rays are simulated through Z-Pinch phenomena.
- New developments at government laboratories is progressing to temperatures capable of causing thermonuclear reactions.
- Such technology could be applied to develop advanced thruster designs that promise high thrust/high specific impulse propulsion
- This project would develop a conceptual design for such a thruster.

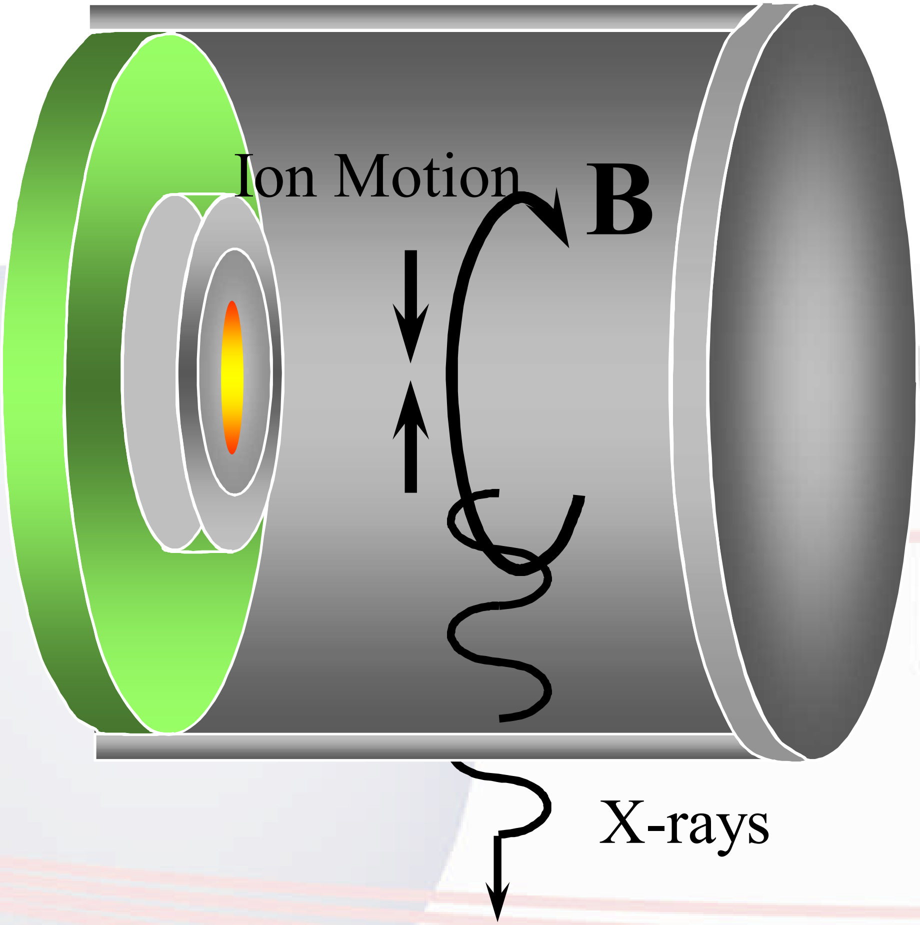
Operation of a Z Pinch



High Current Generates Intense Magnetic Fields

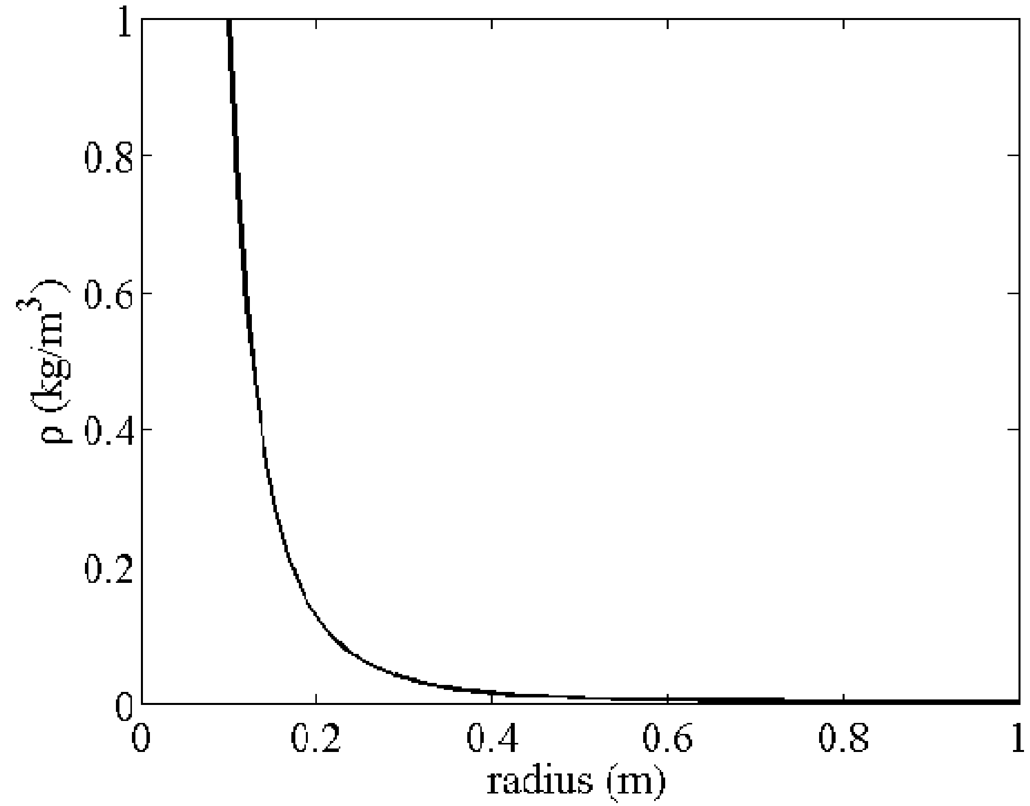


Magnetic Fields Compress the Plasma to X-Ray Temperatures



Plasma Instability

- Rayleigh-Taylor is most deleterious effect preventing success, can be overcome with tailored density profile*

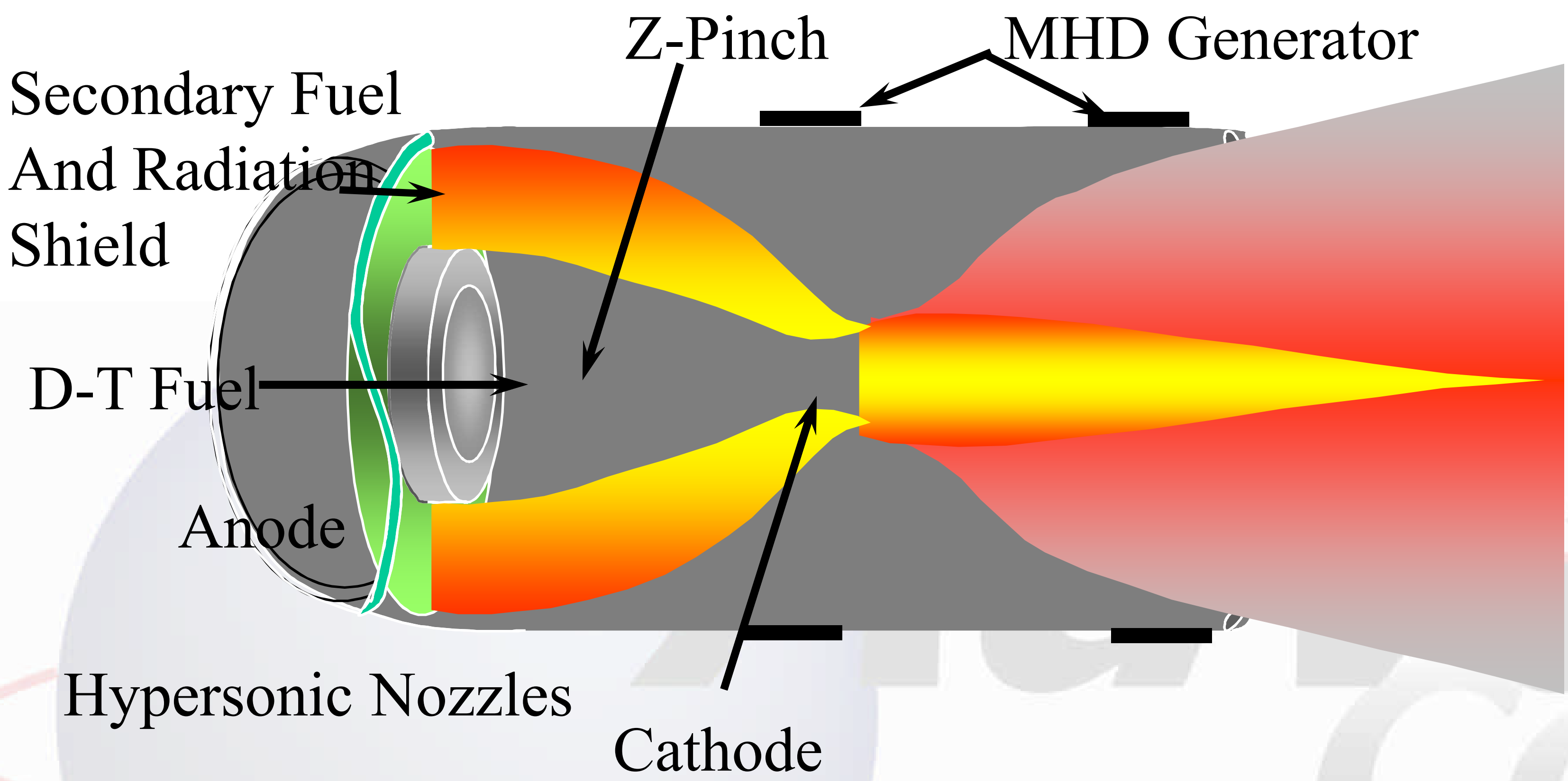


*Velikovich, Cochran, and Davis, Phys. Rev. Let. 77(5) 1996.

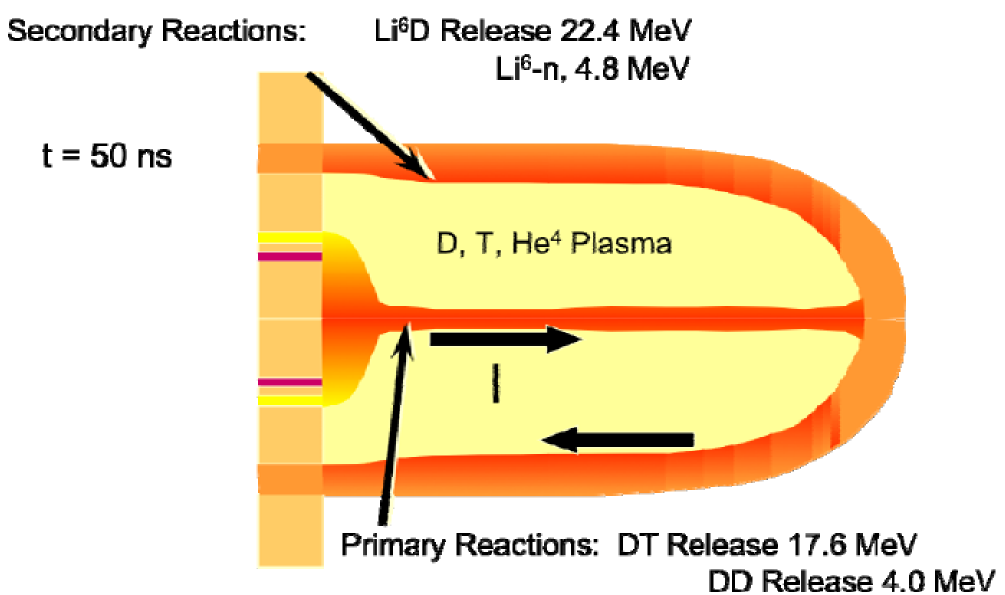
Electrode Erosion

- Coupling electrical energy to plasma
  - Directly coupled devices lead to erosion
  - All susceptible to x-ray radiation and neutron damage
- Potential workarounds
  - Allow electrodes to erode!
  - Consider inductively coupled techniques

Thruster Concept



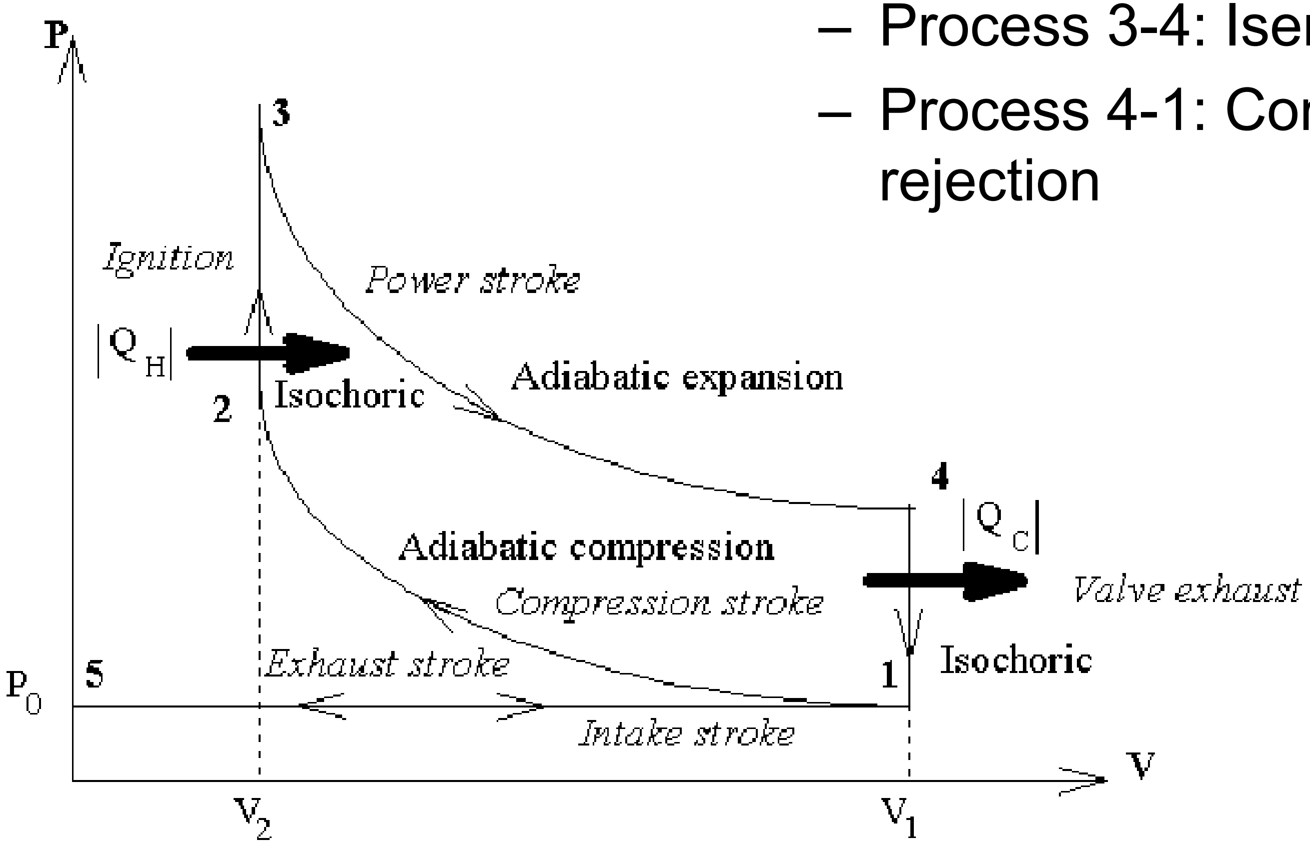
Z-pinch Design



- Annular nozzles with Deuterium-Tritium (D-T) fuel in the innermost nozzle
- Lithium mixture containing Lithium-6/7 in the outermost nozzle.
- The D-T fuel and Lithium-6/7 mixture acts as a cathode

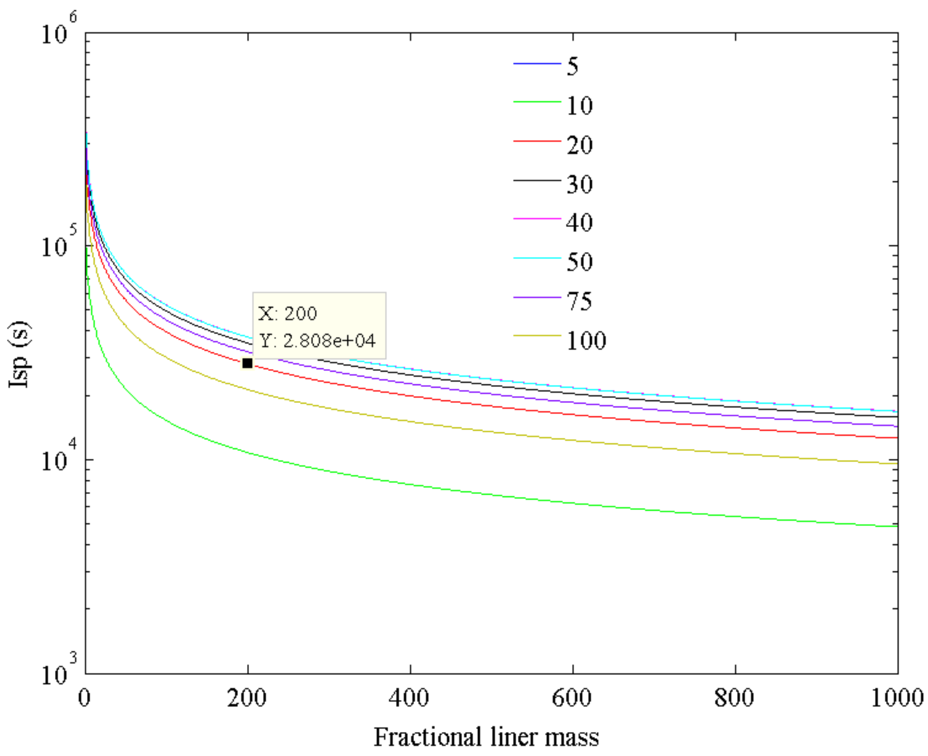
Z-pinch modeling

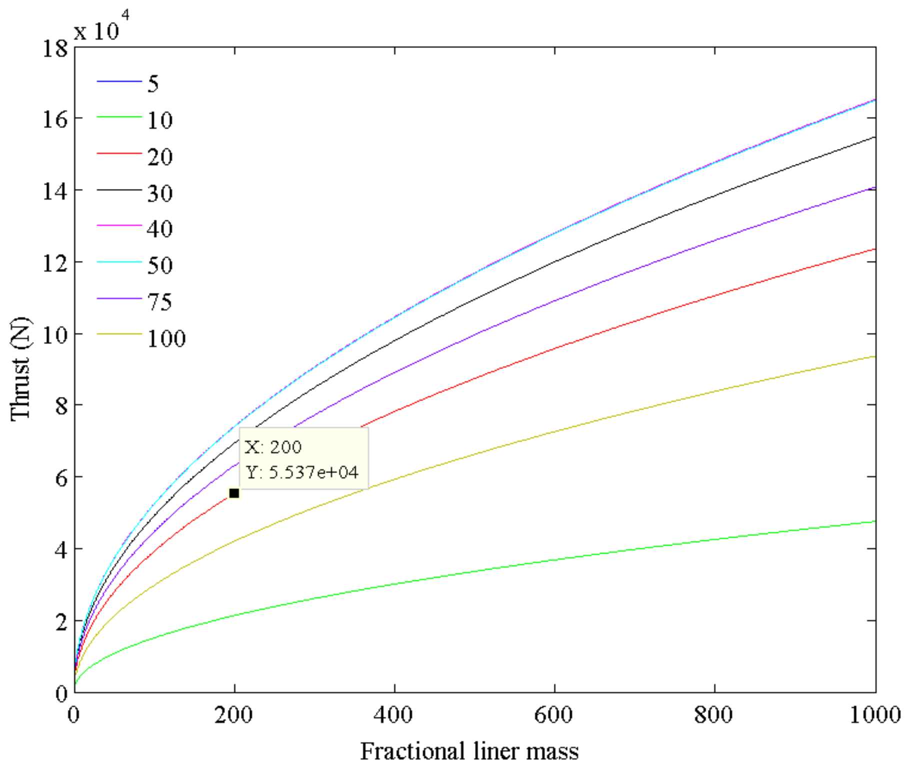
- Treat Z-pinch as Otto cycle
  - Process 1-2: Isentropic compression
  - Process 2-3: Constant volume heat addition
  - Process 3-4: Isentropic expansion
  - Process 4-1: Constant volume heat rejection



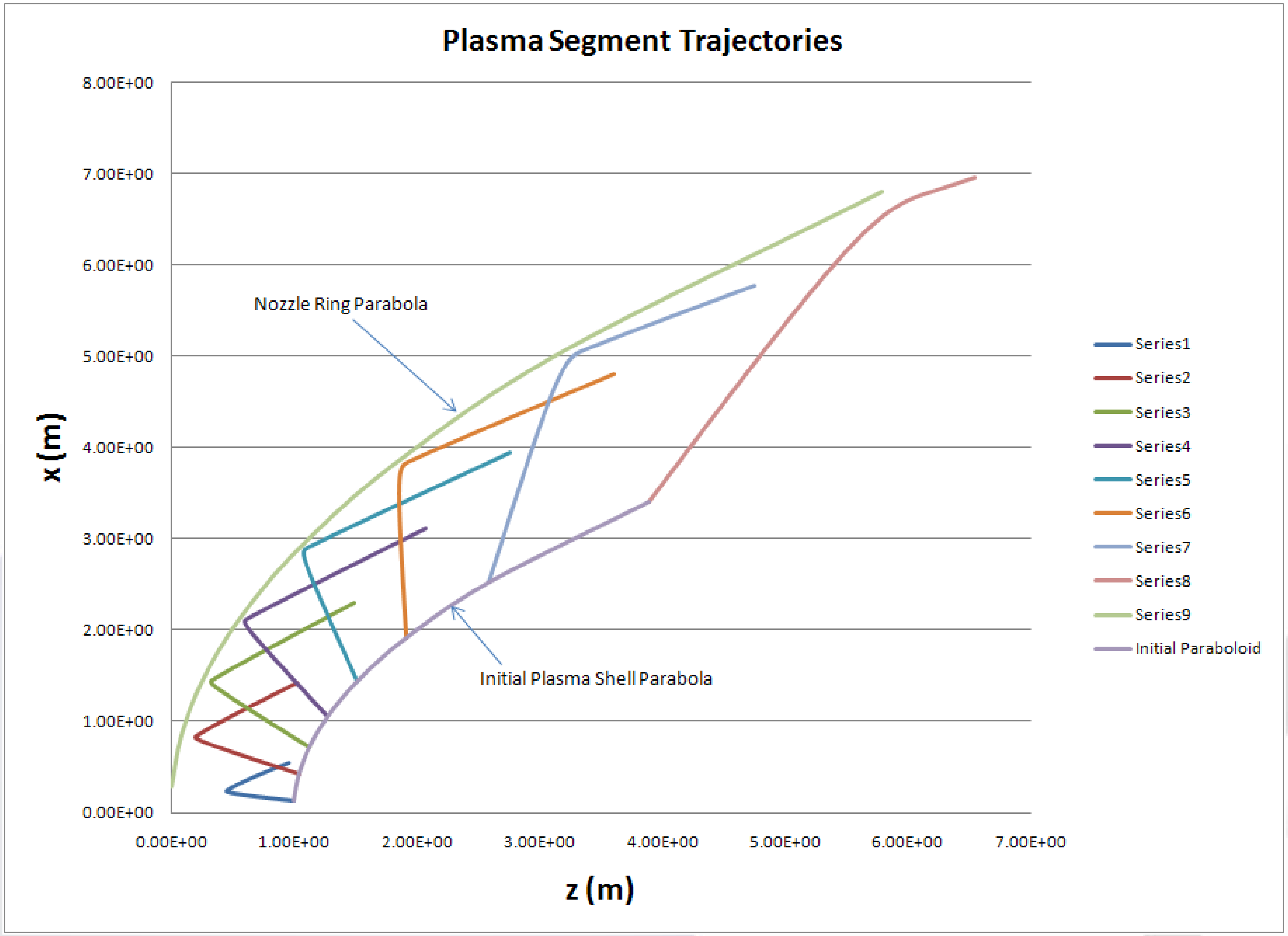
Engine Performance

- Engine Performance as a function of liner mass



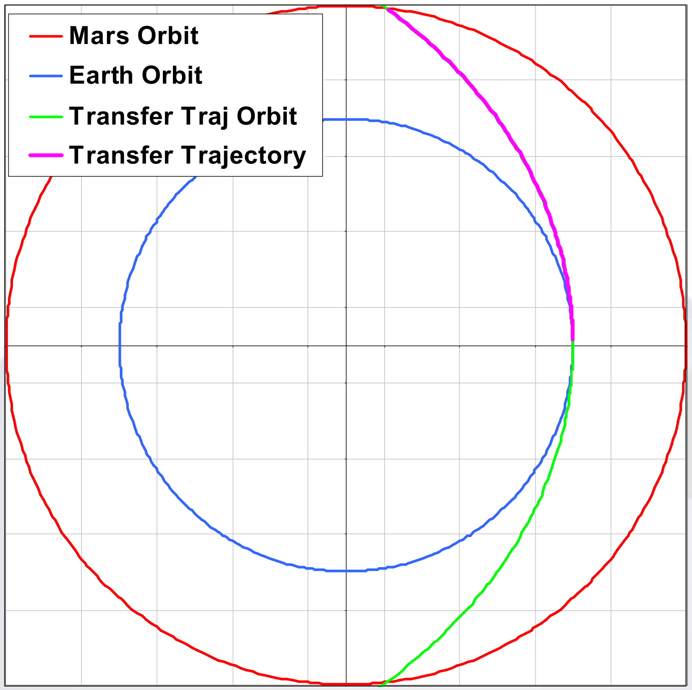


Nozzle Performance



Mission Analysis

	Mars 90	Mars 30	Jupiter	550 AU
Outbound Trip Time (days)	90.2	39.5	456.8	12936
Return Trip Time (days)	87.4	33.1	521.8	n/a
Total Burn Time (days)	5.0	20.2	6.7	11.2
Propellant Burned (mT)	86.3	350.4	115.7	194.4
Equivalent DV (km/s)	27.5	93.2	36.1	57.2



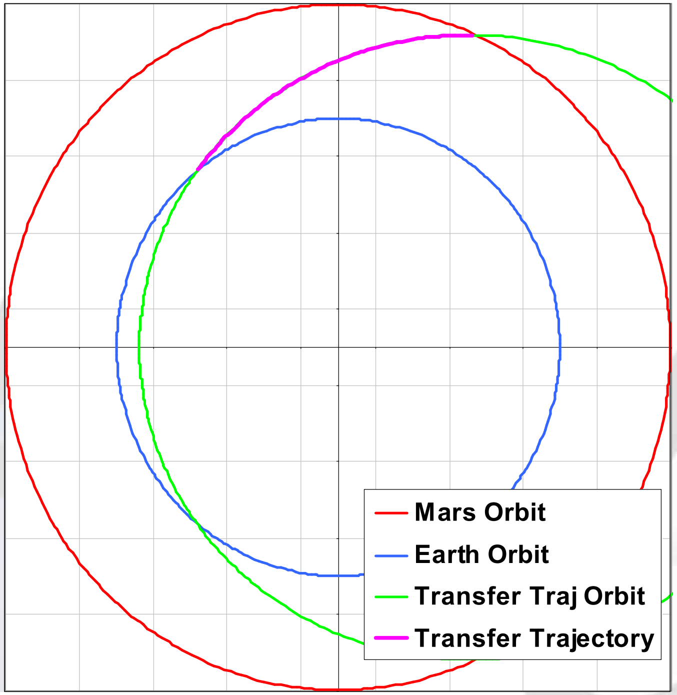
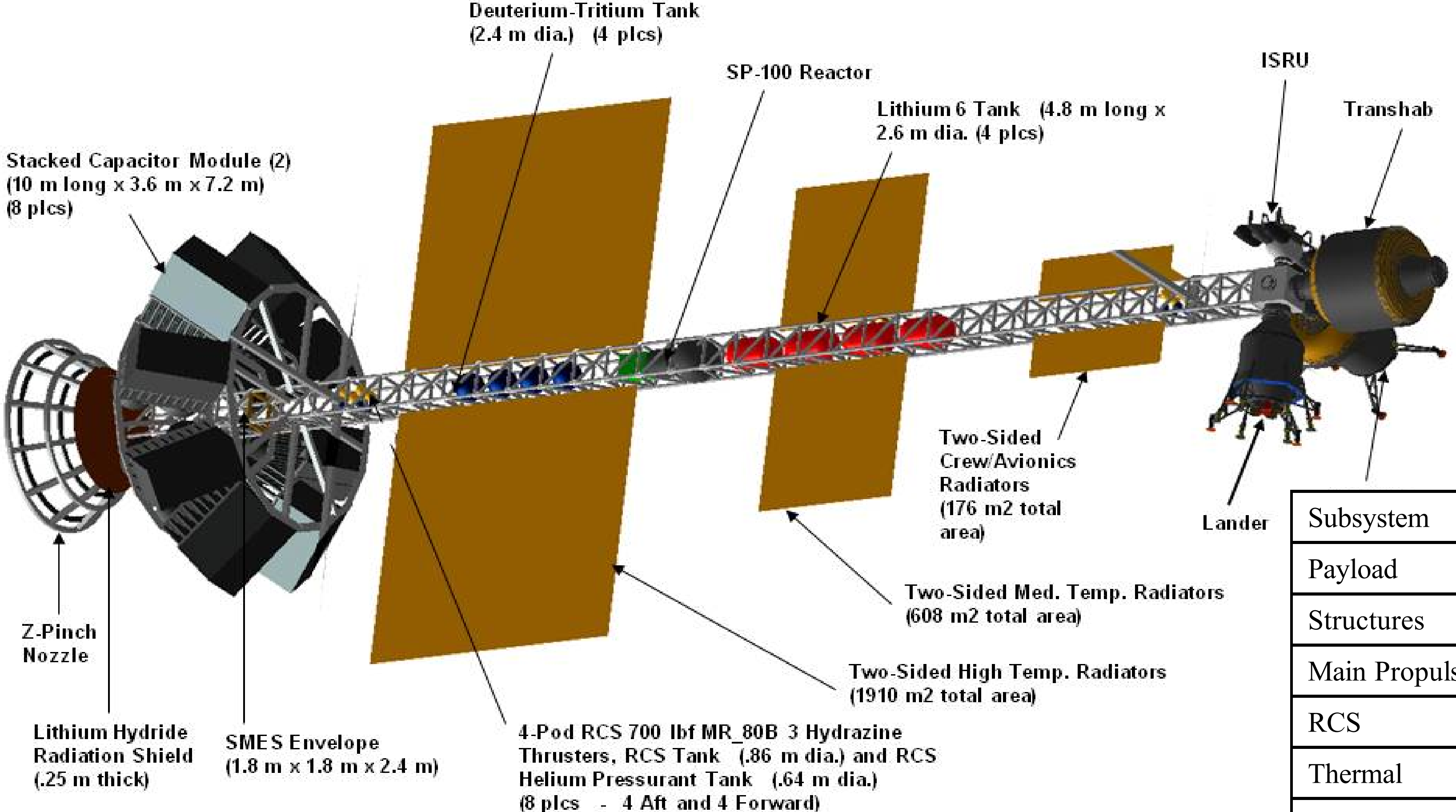


Figure 4.1 Mars 90 Day Transfer Trajectories

Vehicle Configuration



Subsystem	Mass (kg)
Payload	150,000
Structures	54,600
Main Propulsion	95,138
RCS	586
Thermal	77,164
Power	16,480
Avionics	389
Total Dry Mass	394357
30% MGA	73,307
Total Mass	467,664

Thrust Coil Configuration

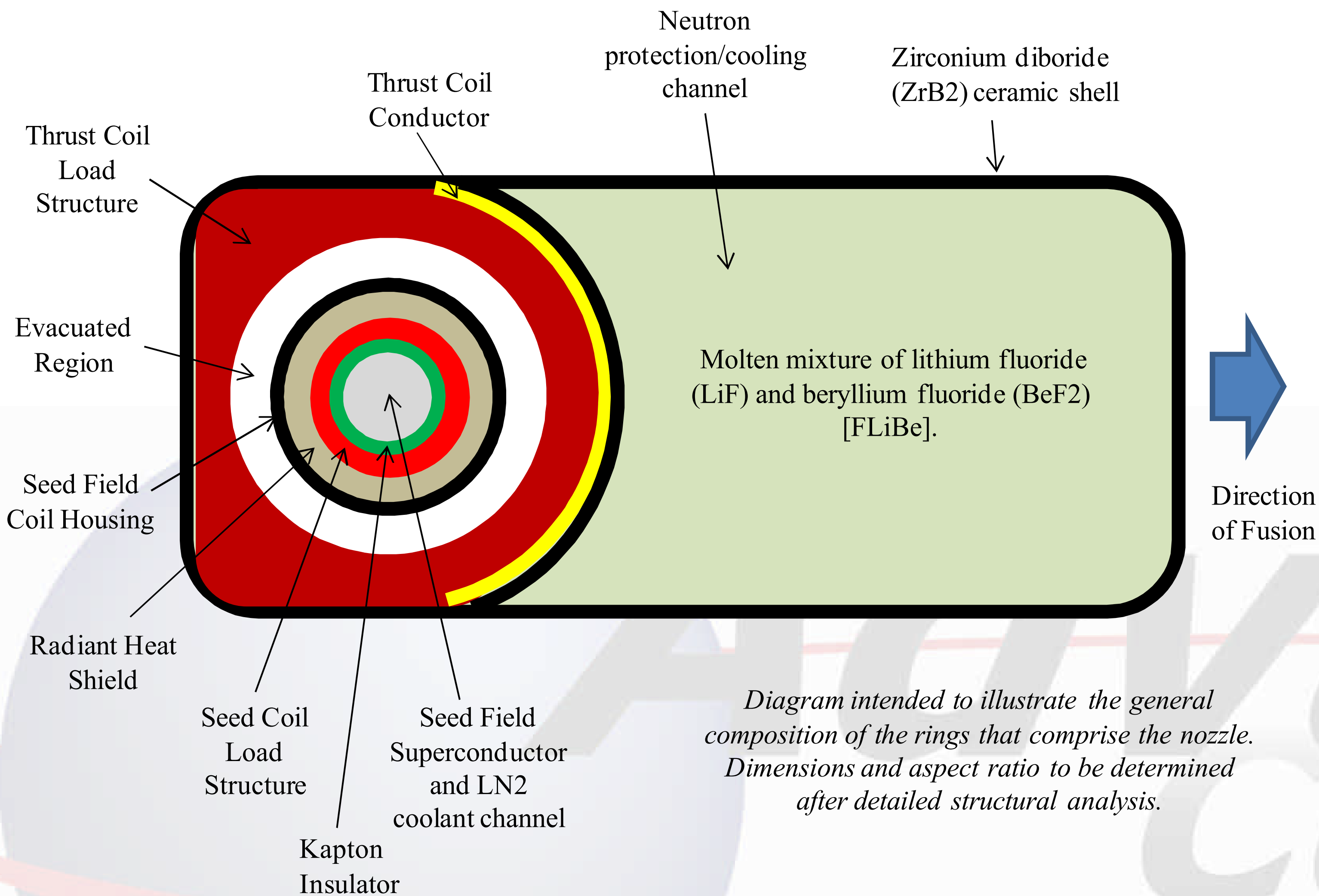
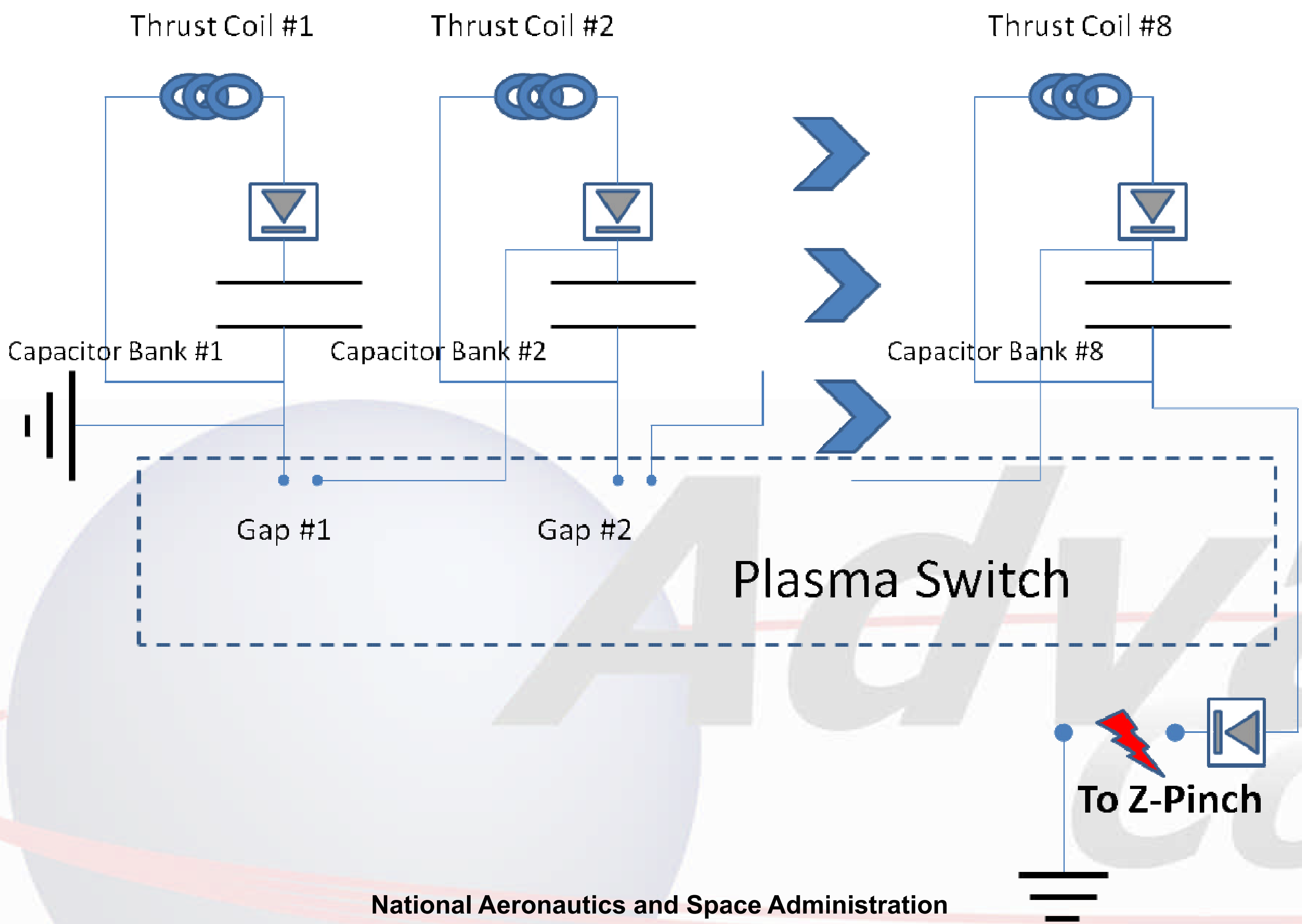
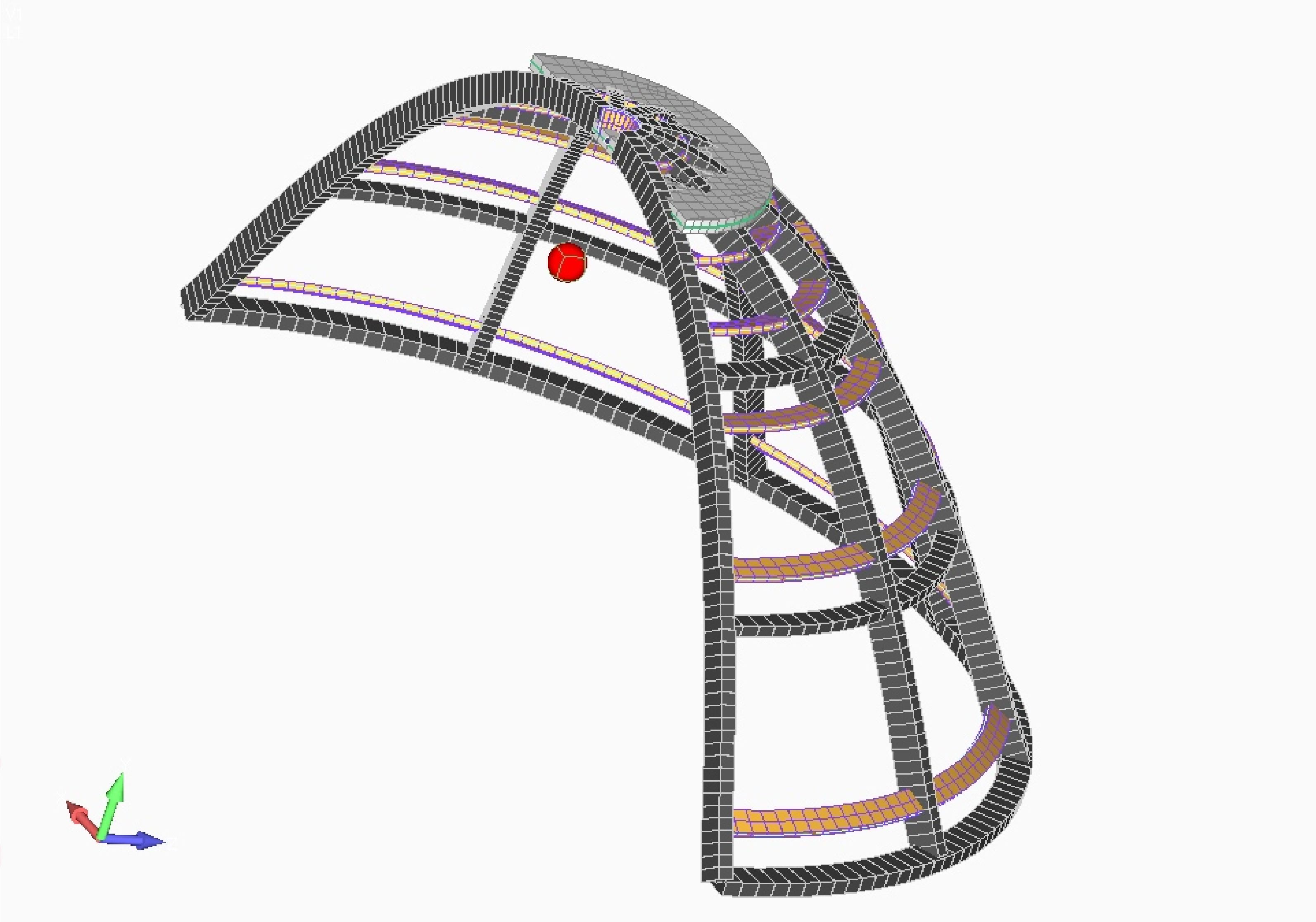


Diagram intended to illustrate the general composition of the rings that comprise the nozzle. Dimensions and aspect ratio to be determined after detailed structural analysis.

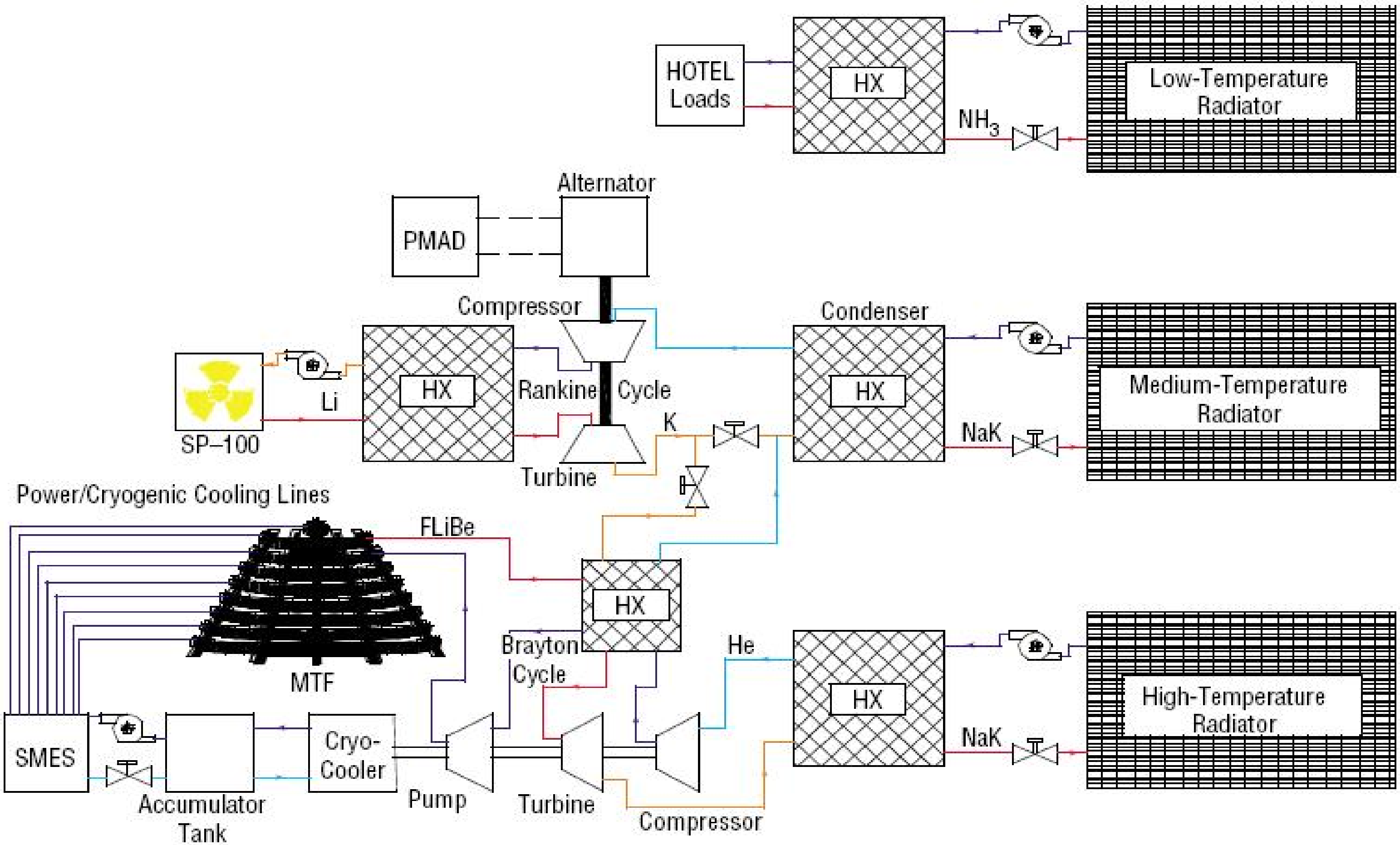
Power Management System



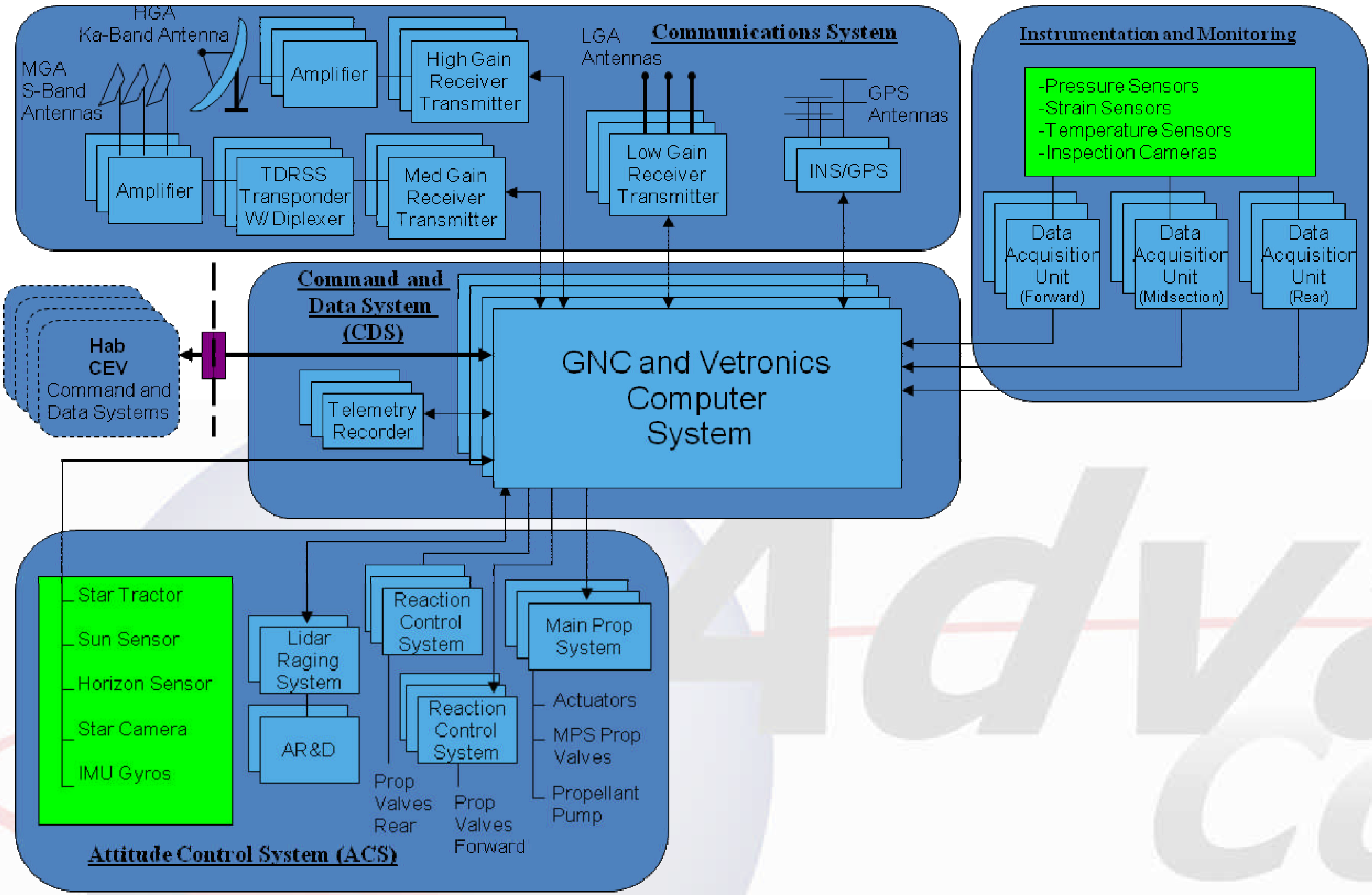
Structural Analysis of Magnetic Nozzle



Thermal Management System

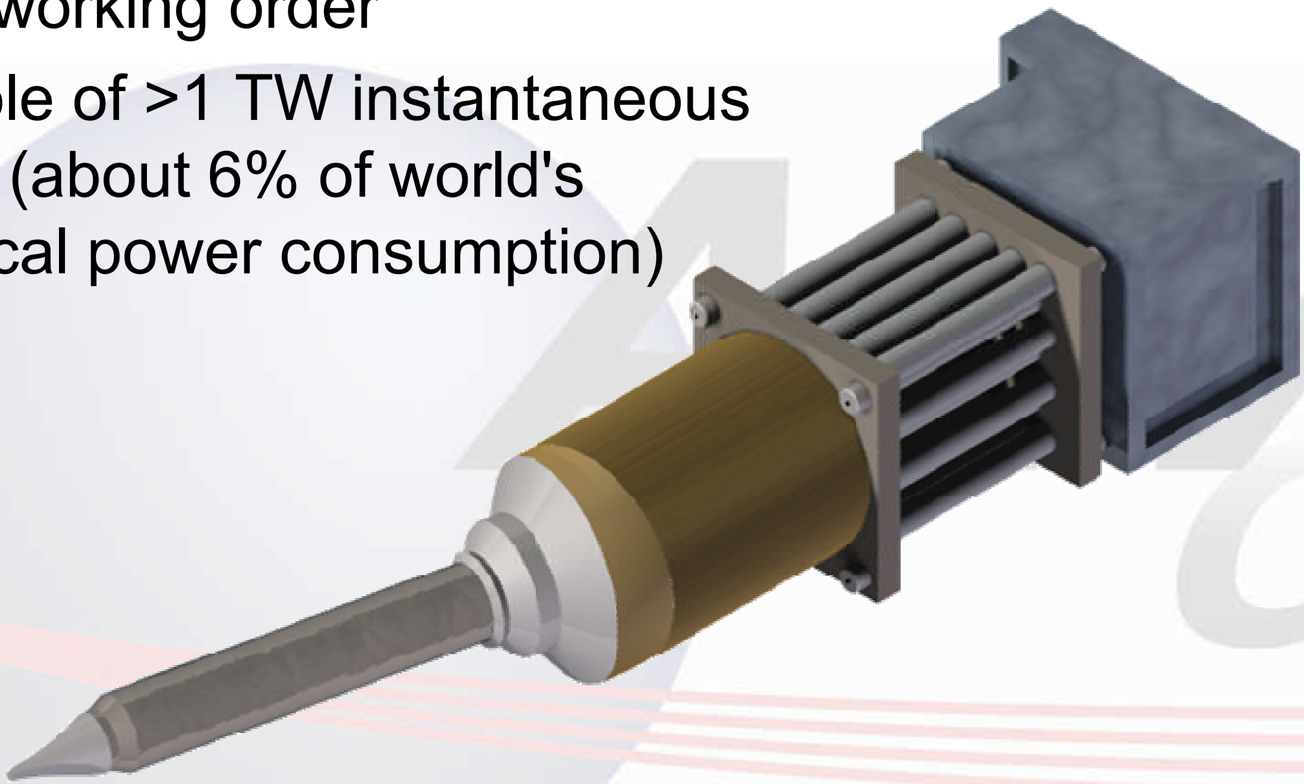


Avionics Suite



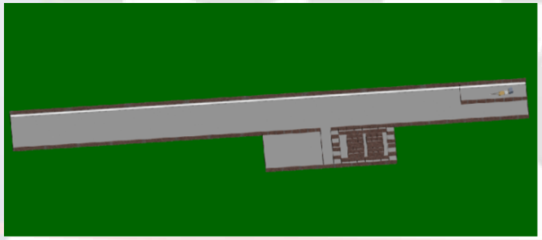
DECADE Module II

- 500 kJ pulsed power facility
- Last prototype built before DECADE construction
- Defense Threat Reduction Agency
  - Nuclear Weapons Effects (NWE)
  - Plasma Radiation Sources (PRS)
- Good working order
- Capable of >1 TW instantaneous power (about 6% of world's electrical power consumption)



Pulsed Fusion Facility

- DM2 Utilization Arrangements
  - L3 Communications, Pulsed Science Division
  - Boeing
  - Oak Ridge National Labs
- Other fusion collaborations
  - LANL
  - HyperV Corp.
  - Univ. of New Mexico
- Expected Capabilities
  - 500 ns pulse, 2 MA current
  - 1 keV, 10^{25} /m^3 plasma state
  - Effective dwell time of ~100 ns



Aerophysics lab